Optical lattices: the measurement problem

J. J. García-Ripoll

IFF, CSIC Madrid

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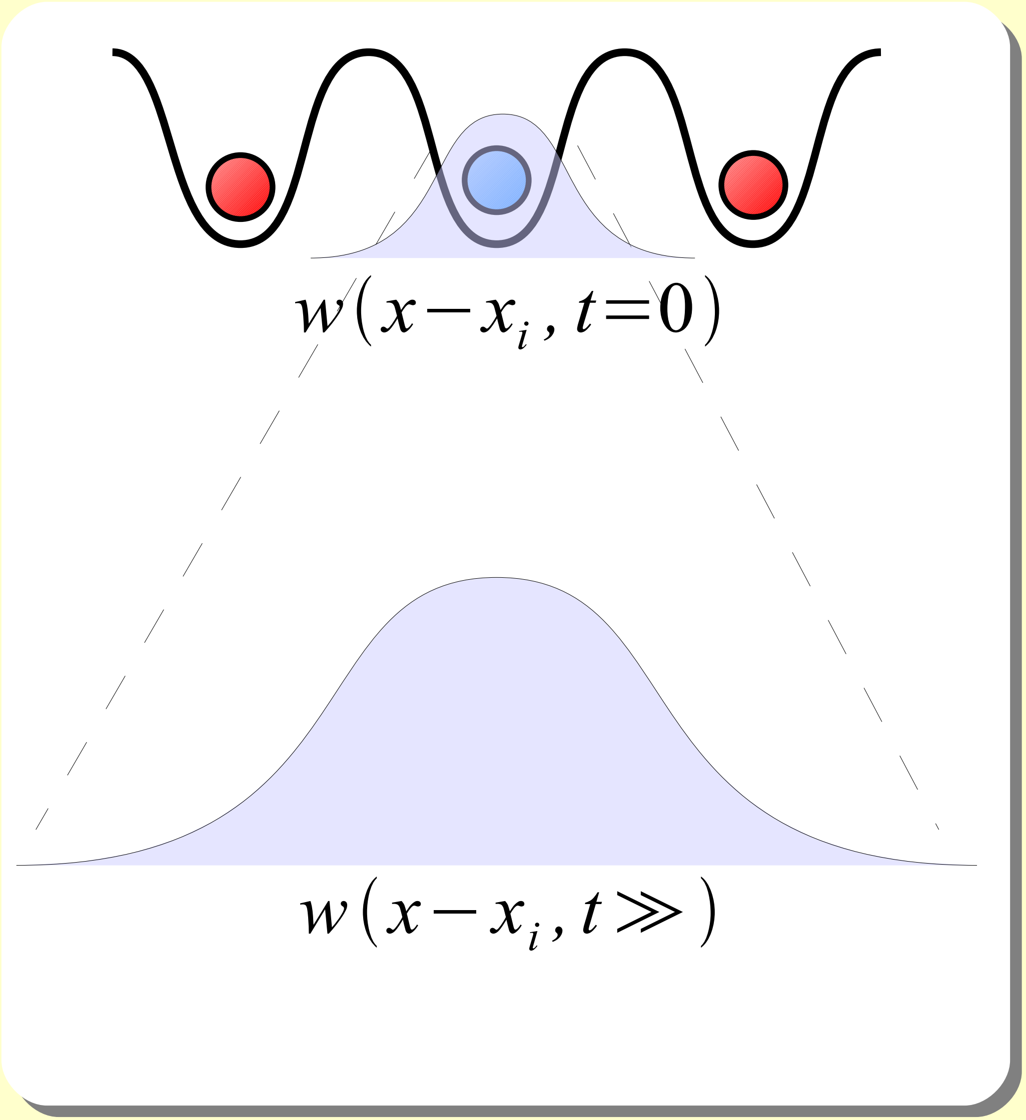
Time of flight images

- If we switch off the lattice, the atoms will expand.
- Since interactions are weak, we may approximately write

$$\psi^+(x,t) \simeq \sum_i w(x-x_i,t)\, a_i^+$$



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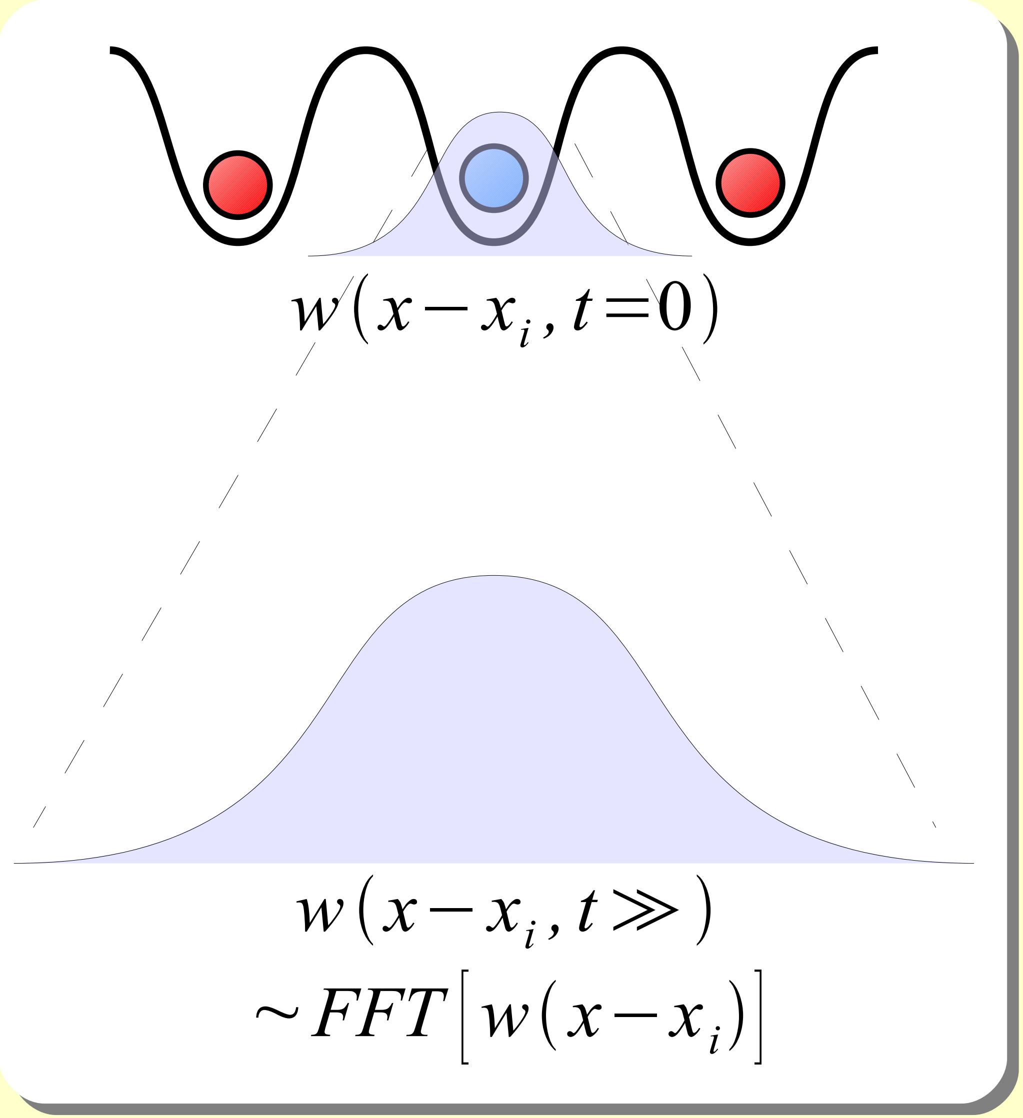
- For long times, the wave behaves like a light wave: it diffracts
- At long times we recover its Fourier transform



Time of flight images

- The resulting density profiles exhibit interference fringes

$$|\tilde{w}(q)|^2 \sum_{j,k} \langle a_j^+ a_k \rangle e^{iq|j-k|a}$$

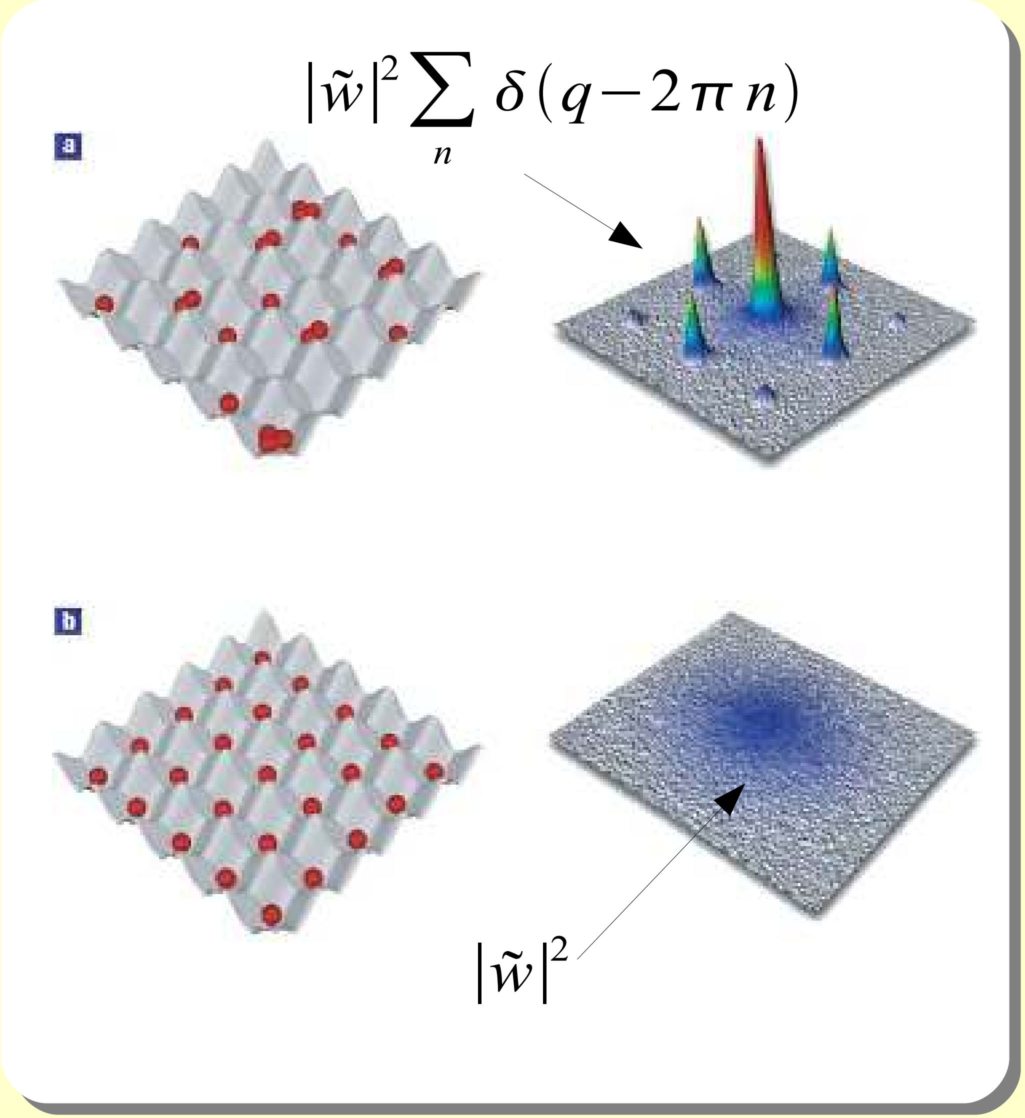
where $|\tilde{w}(q)|^2 \sum_{j,k} \langle a_j^+ a_k \rangle e^{iq|j-k|a}$

- For a superfluid

$$\langle a_j^+ a_k \rangle \simeq n$$

- For a Mott insulator

$$\langle a_j^+ a_k \rangle \simeq \delta_{ij}$$



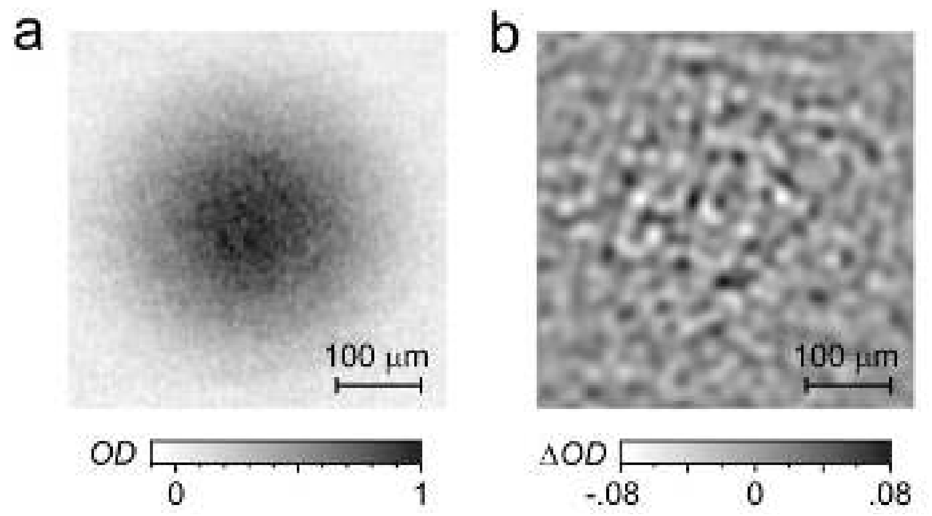
Immanuel Bloch, Nature Physics **1**, 23 - 30 (2005)

Noise correlations

- We know that

$$\hat{\rho}(x)_{t\to\infty} \sim \hat{\rho}(q, t=0)$$

- From a single image, we measure a value of $\hat{\rho}(q)$



M. Greiner et al, Phys. Rev. Lett. 94, 110401 (2005)

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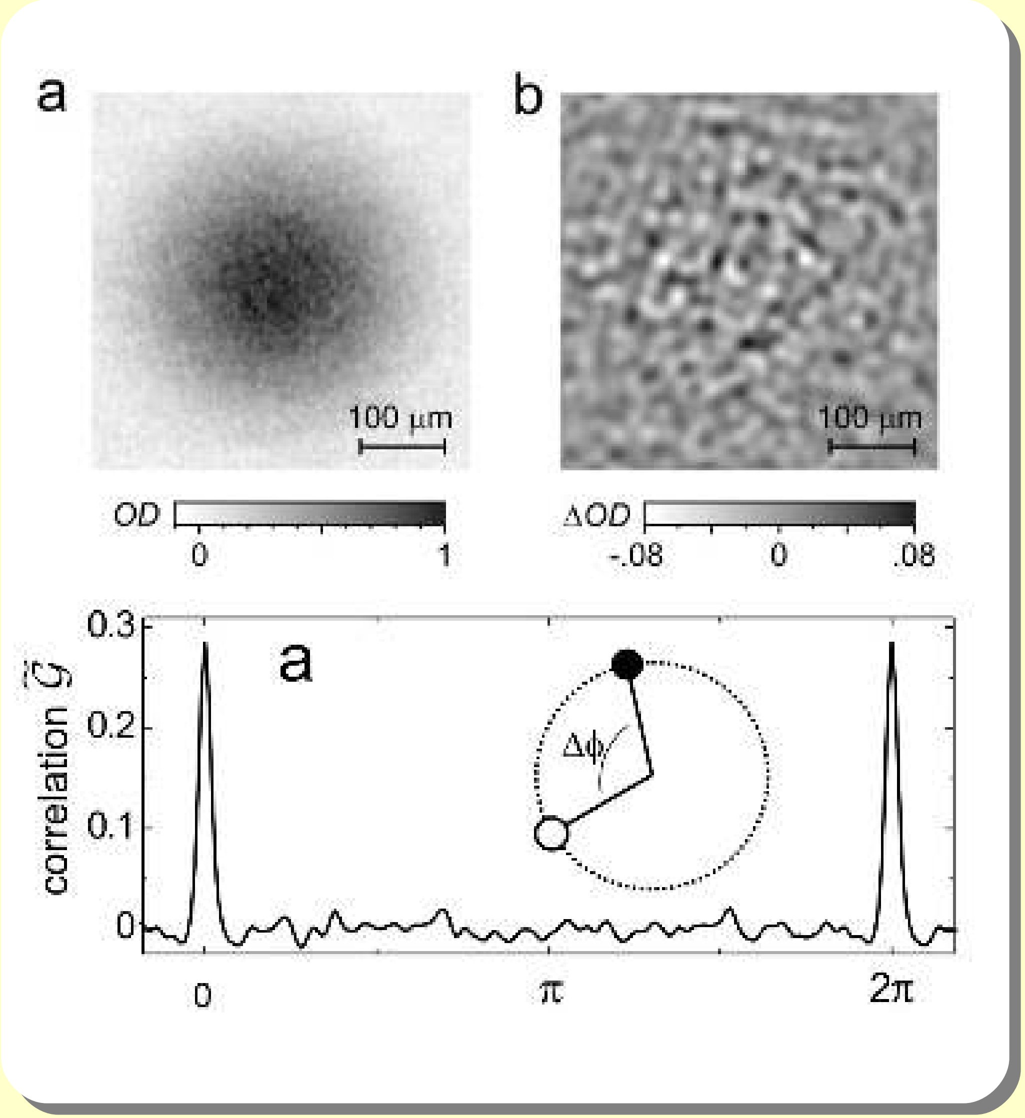
higher order correlations.



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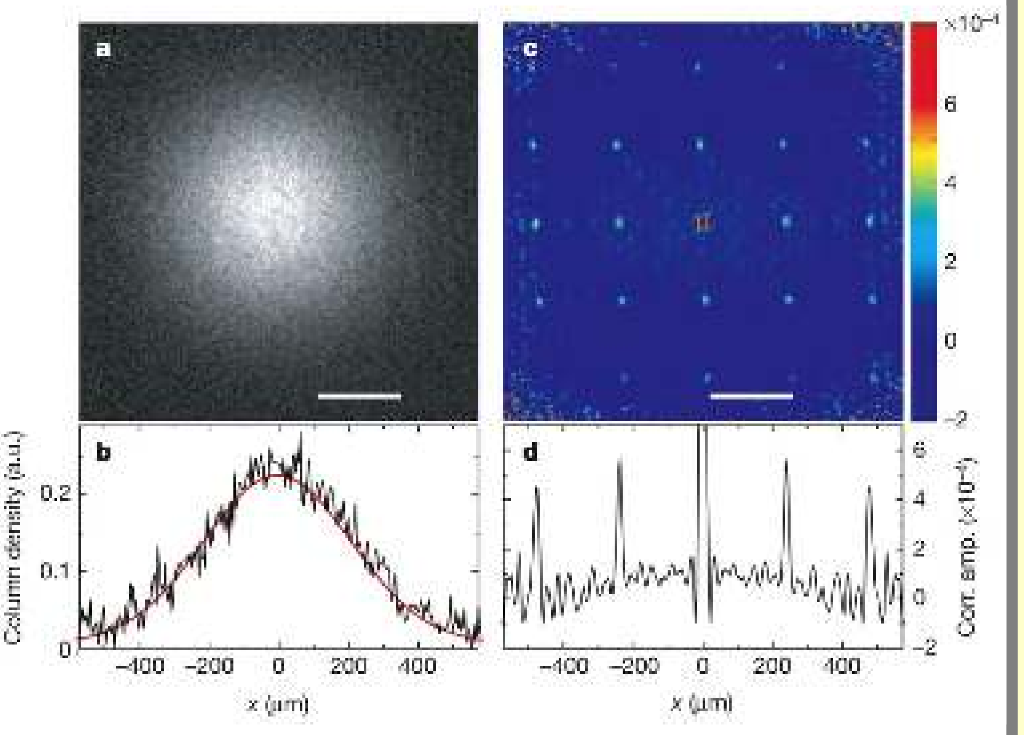
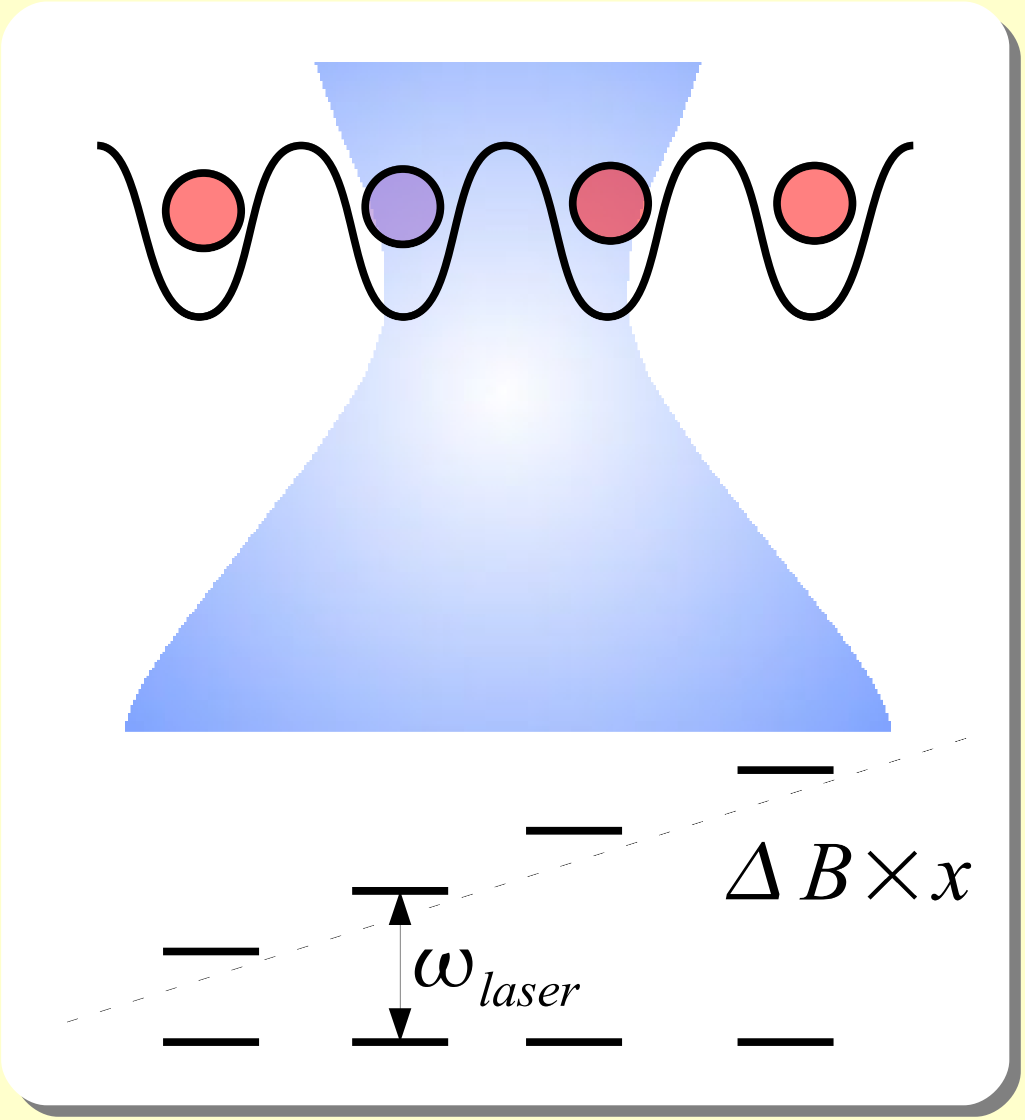


S. Fölling et al, Nature, **434**, 481 (2005)

Beating the addressing limits

Spectroscopic addressing

- We do not have yet optical access to the individual lattice sites.
- We have seen how to address them spectroscopically.
- But this cuts slices across the lattice:
  - no site by site measurements

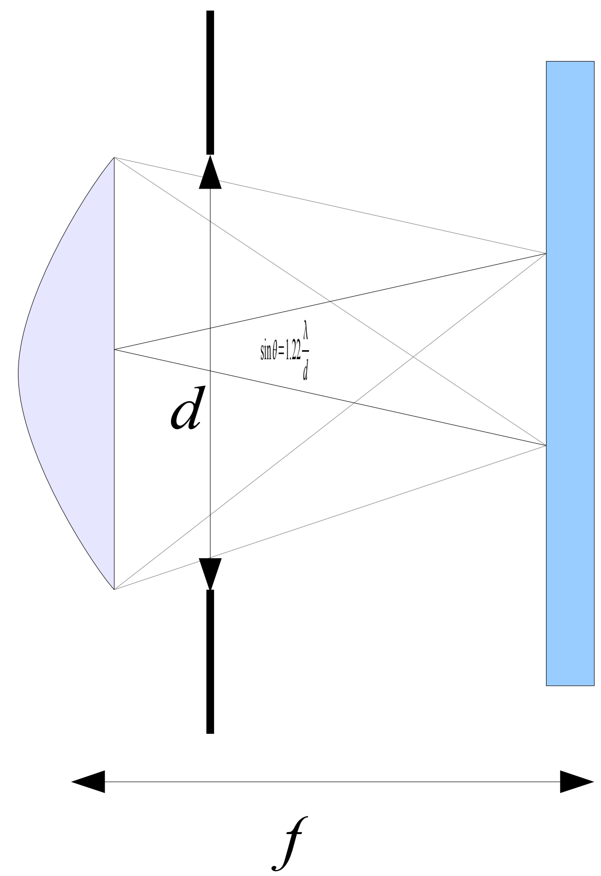


Diffraction limit

- Smallest feature we can resolve (diffraction limit or Airy disk) is also the focusing limit of the optical setup.
- Angular resolution limit

$$\sin\theta = 1.22\frac{\lambda}{d}$$

- The maximum resolution of a microscope image



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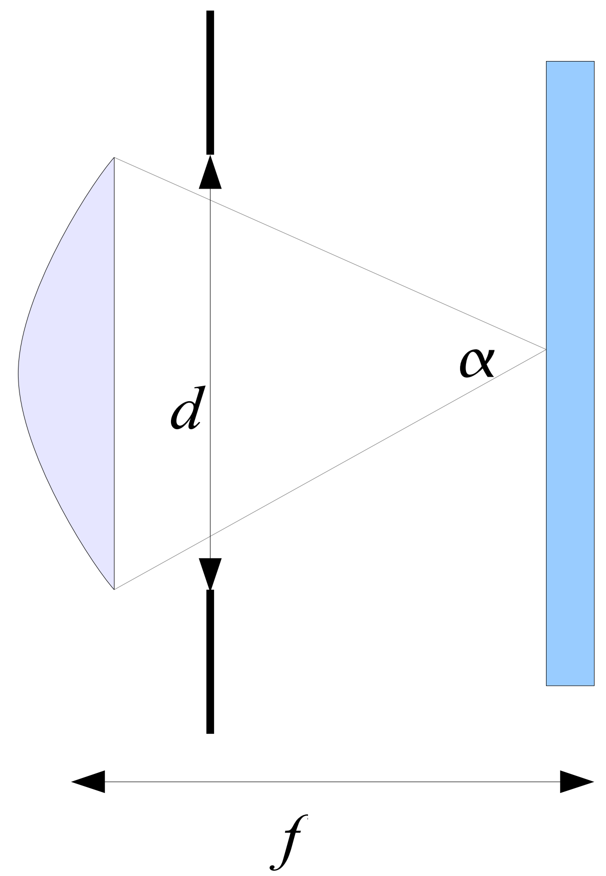
$$\sin\theta = 1.22\frac{\lambda}{d}$$

- For a microscope

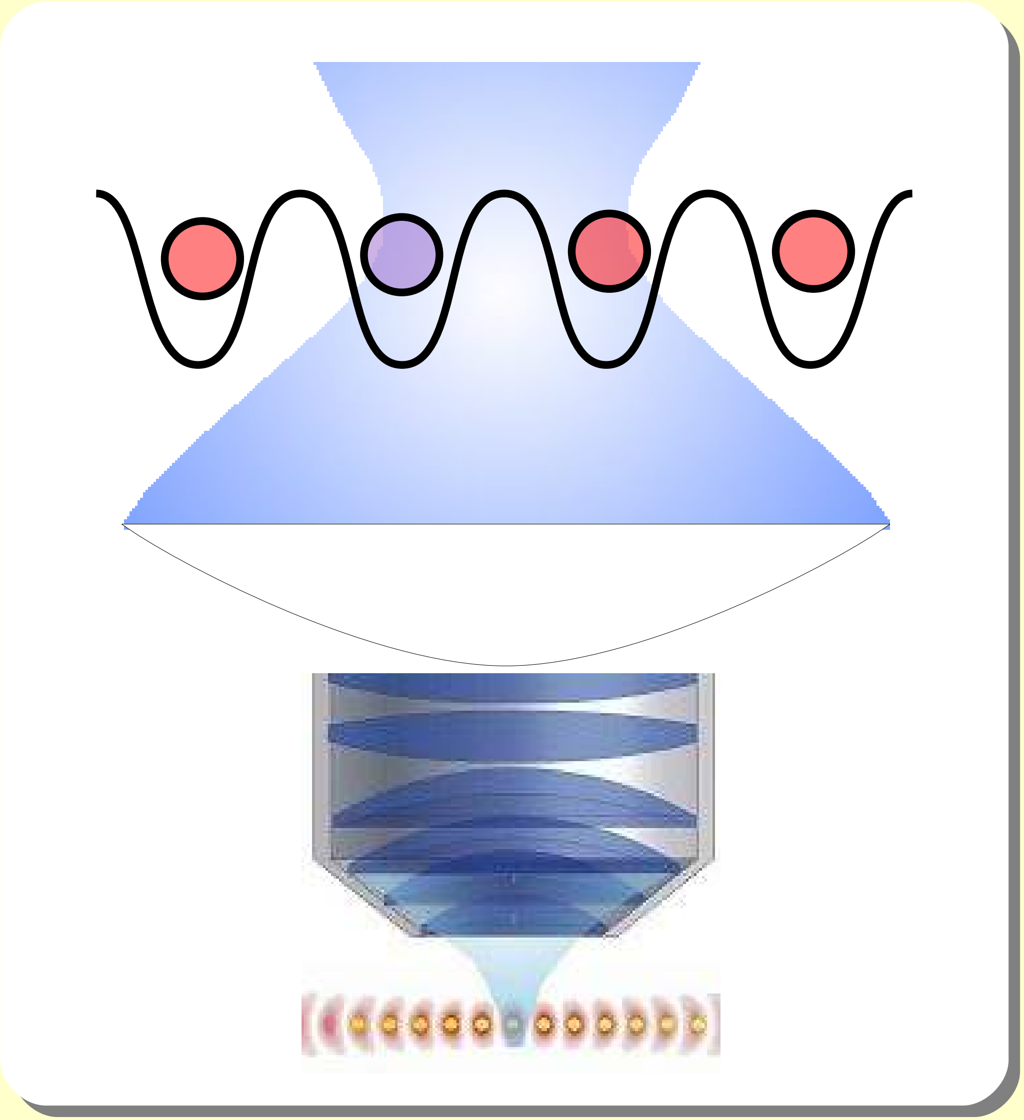
$$R = \frac{1.22\lambda}{2\,N.A.} = \frac{1.22\lambda}{2\,n\sin(\alpha)}$$

realistically, maximum is about half a wavelength for very large aperture.



Solution 1: microscopy

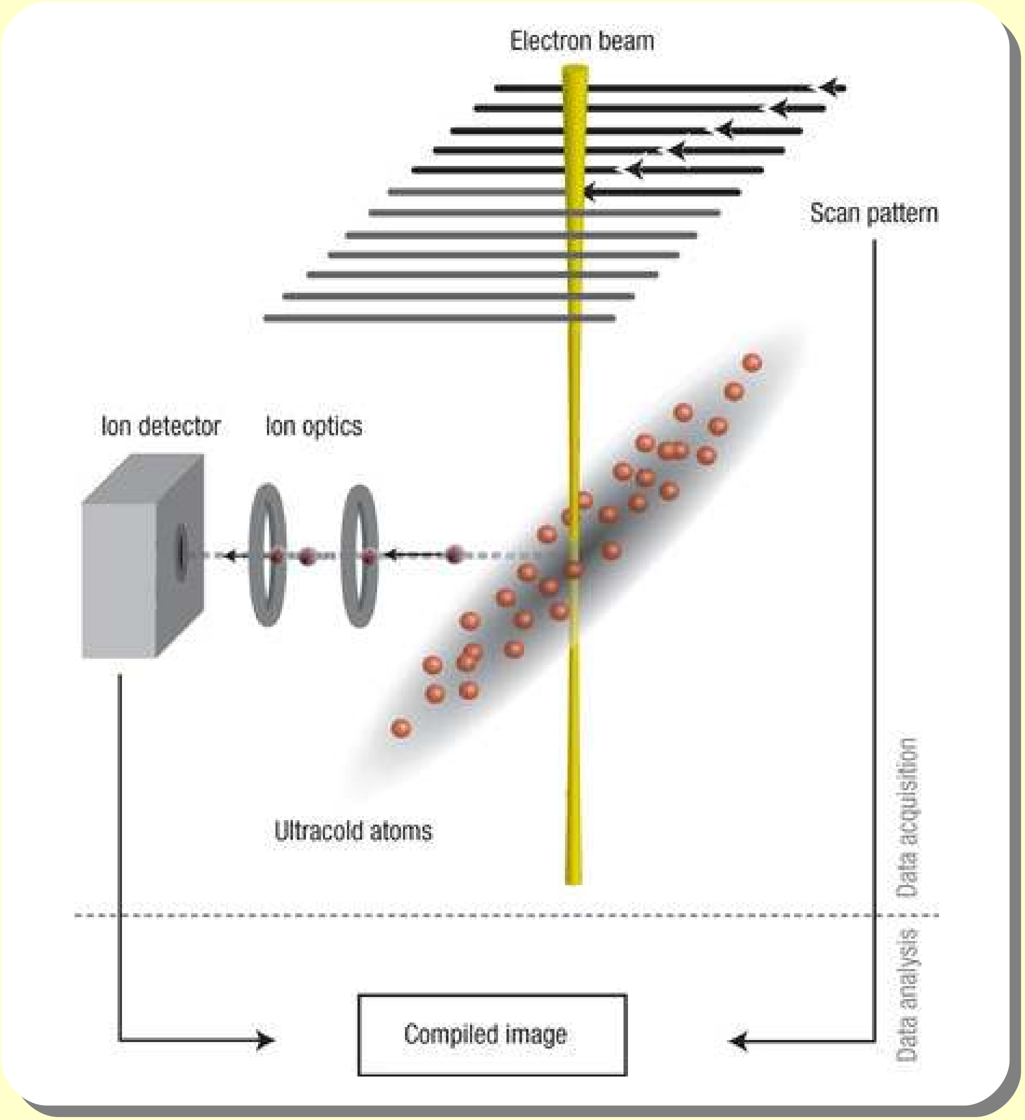
- Ongoing experiments aim at creating a single layer of atoms.
- Trapped by evanescent forces above a cristal.
- Addressed by a strong microscope
- Very close to lense, very large numerical aperture
- Very small signal, delicate experiment



Ongoing work at I. Bloch's and M. Greiner's groups.

Solution 2: other imaging tools

- Use electrons to illuminate individual atoms
  - Shorter wavelengths
  - Very good focusing
  - Single-site addressability
- But
  - Destructive
  - No discrimination of atomic state (yet)



T. Gericke et al, Nature Physics **4**, 949 (2008)

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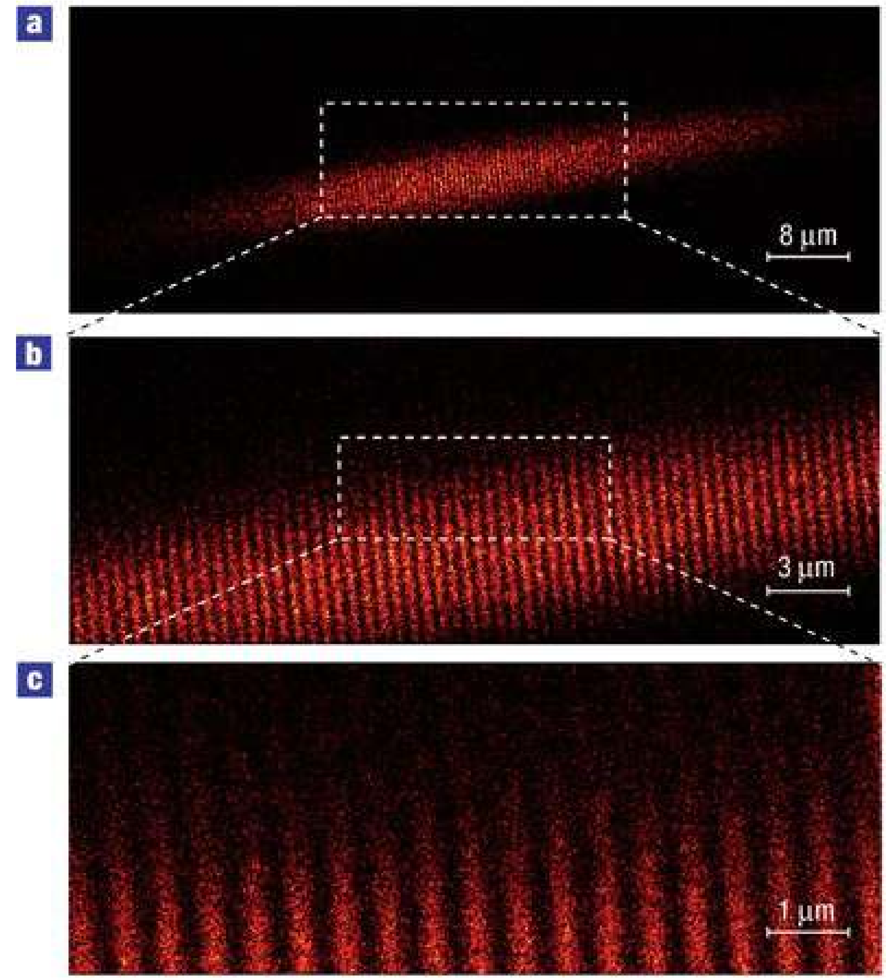

T. Gericke et al, Nature Physics **4**, 949 (2008)

Solution 3: quantum operations